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Common walnut (*Juglans regia* L.) wood characteristics in two Italian plantations

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Abstract - The Woodnat project (H2020) has the goal of identifying the problems that led to poor yields in walnut plantations established under the financial support of EU 2080/92 Regulation and Rural Development Programme, and of improving the market demand for smaller assortments. Some of the plantations monitored in the framework of the project needed thinning: one, an experimental stand with 5 plots with different layouts and species established in 1994, was thinned in spring 2018; in a second one, a polycyclic plantation established in 1996 with common walnut, hybrid poplar and nurse trees, the walnut was thinned in spring 2017. At thinning, sample disks were taken at the base of 5 trees randomly selected at each site for the determination of density and shrinkage in the radial, tangential and longitudinal direction. The average density was 0.52g/cm3; the average tangential shrinkage was 12%, while the average radial shrinkage was 6.7%. There were differences in behaviour between the samples from the two sites, probably due to different vegetal materials, age of the plantations and cultivation models.

Keywords - walnut; thinning; wood characteristics; polycyclic plantations.

Introduction

Over recent decades in Europe, under the financial support of EU Regulation 2080/92 and of Rural Development Plans, new wood plantations have been established for the production of valuable hardwood for industrial use. In Italy, in the period 1994-2000, 104,000ha of new wood plantations were established, to which another 40,000ha have been added, starting from 2001, financed by the Rural Development Programme, (AA.VV. 2008).

The mainly woody species planted were walnut (*Juglans* spp.) and other valuable broad-leaved and nurse trees such as cherry tree (*Prunus avium* L.), oak (*Quercus robur* L.) and ash (*Fraxinus* spp.). Before this period, the main intensively managed wood plantations in Italy were mostly pure poplar stands, pruned with methods developed for selected clones, and harvested after 10-12 years (Bisoffi 1998, Bisoffi 1999).

The first woody plantations established with noble hardwood species were either pure, with various spacing and realised utilising seedlings of non-selected material (Barreca et al. 2010) or mixed plantations with two or more principal species (Bisoffi et al. 2009); due to a lack of knowledge of both nursery and cultivation practices, many stands did not meet their production goals, providing low quality wood, obtained from small trees, poorly pruned and with phytosanitary problems (Calvo 2011). In the following years, the genetic resources for the nurseries were improved, selecting seedlings with good growth and shape characteristics, and new improved cultivation models were applied, such as mixed models with nurse trees and polycyclic plantations (Buresti Lattes et al. 2001, Clark et al. 2008, Mori 2014). After about 25 years, some of these plantations needed to be thinned, to widen the space available for the trees that would have to mature, thus favouring a continuous and homogeneous radial growth of the stems (Bianchetto et al. 2013, Frattegiani 2002, Marchino and Ravagni 2007). In many cases, considering the plantation layout, about 30-50 % of the trees have to be thinned, producing a high quantity of raw material available for the market. Unfortunately, due to the poor quality and small size of the wood collected and to the lack of demand from the market, which prefers oak or black walnut, (*Juglans nigra* L.), the wood of common walnut (*Juglans regia* L.) derived from thinning is generally sold as biomass for energy, with a consequent poor income (that hardly covers the cost of thinning).

The 'Woodnat' project ('Second generation of planted hardwoods forests in the European Union'), financed by the EU programme Horizon 2020,

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Figure 1 - Stand A (on the left) and stand B (on the right).

has the goal of evaluating the problems of walnut cultivations that led to such poor yields, and of improving the market demand also for the smaller assortments, making them suitable and interesting at industrial level (on-line: https://www.woodnat.eu). As a first step, knowledge of the characteristics of the wood of common walnut resulting from thinning operations in the plantations described above can help the search for new possible uses and for innovative products, also in the design sector (Cremonini and Zanuttini 2009). The project made it possible to collect some samples of walnut wood derived from the thinning of a pure and a mixed plantation considered in the project, and to determine some of its characteristics. These data, useful for the evaluation of wood suitability for industrial purposes, are described in this paper.

Materials and methods

Some of the plantations monitored within the project needed to be thinned in spring 2018 to maintain a constant and balanced diametric growth; two of these, managed and monitored by the Italian association for environmental and economic sustainable wood production (AALSEA - https://www.aalsea.it/), showed good growth and quality results: one (plantation A), established in 1992, is an experimental stand with 5 plots with different layouts and species; the first plot is cultivated with pure common walnut (*Juglans regia* L.) with a regular initial spacing of 8 × 8m; weed control was performed during the first 10 years, and pruning was concluded at the 4th year, cleaning the stems up to about 3.5m. This plantation was thinned in spring 2018, felling about 45% of total trees, on the basis of a method of selective thinning. The other stand (plantation B)

Figure 2 - Two examples of the walnut disks obtained from stands and utilized for measurements.

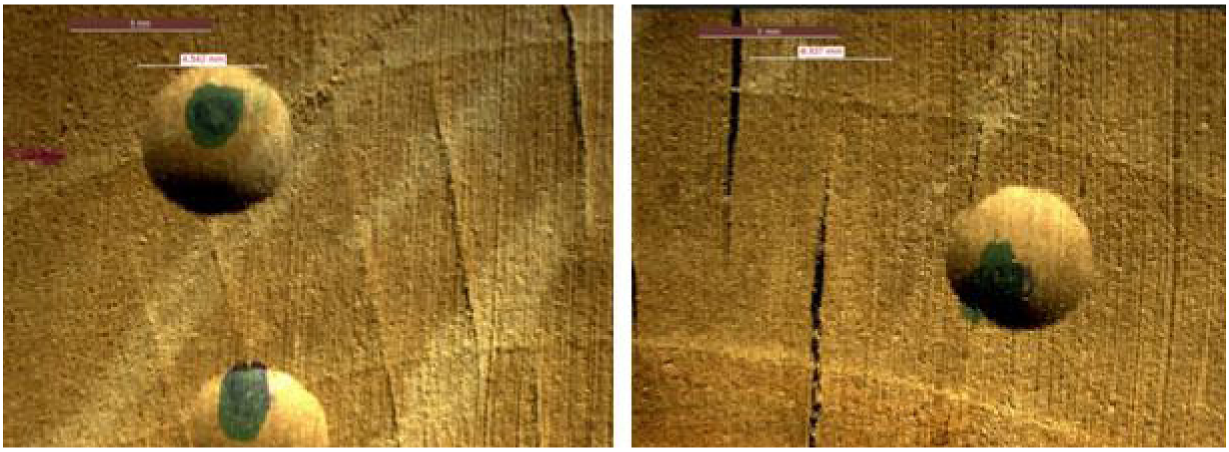

Figure 3 - Hardness tests position: 'on ring limit' and 'in the middle of the ring.

is a polycyclic plantation established in 1996 with common walnut, hybrid poplar (*Populus ×canadensis* L.) and nurse trees, in which poplar trees were harvested in 2007 (Fig. 1). The two plantations are cultivated near Mantua, Italy, in a flood plain of the Oglio river; the area is characterised by deep, silty-sandy soils and by sub-continental climate (mean annual temperature 13.6°C, mean annual precipitation 790mm) (Pelleri et al. 2013)

Weed control and pruning operations required less effort, due to the particular layout, so the trees have a clean stem (without branches) up to about 4m; in this case walnut was also thinned, by felling 45 % of the trees on the basis of a selective method. The trees felled were collected and stacked on the farm, waiting to be sold. For each stand, 5 fresh trunks were randomly selected and a sample disk was taken from the base of each first log. All disks were 5cm thick (Fig. 2), with bark; they were protected with plastic film, to avoid further loss of water, and transferred to the laboratory for testing.

Each disk was photographed for a visual evaluation of size, shape and possible presence and size of heartwood. Then, 2 sapwood test pieces with dimensions 50 × 50 × 50mm were taken from each disk. All the pieces obtained were immediately measured to obtain data on the fresh wood; measurements were then repeated after kiln drying at 103 ± 5°C until constant mass; the following parameters were obtained:

Fresh wood density (g/cm^3), derived from the ratio between wet weight (g) and volume (cm^3) measurements;

Total linear shrinkage in the main anatomical directions (radial, tangential and longitudinal), derived from dimensional measurements before and after drying;

Initial water content, from weighing at the fresh state and after kiln drying at 103 ± 5°C.

All tests were carried out in conformity with the reference standard (ISO 13061-1/2:2014). Density is one of the most important wood characteristics, as it allows one to predict a greater number of other properties (Zobel and Talbert 1984, Bowyer and Smith 1998); closely related to it, such as strength, dimensional stability, ability to retain paint and fibre yield (Wani et al. 2014). The density values obtained were correlated to the shrinkage values in order to evaluate the correlation degree.

The test pieces were then analysed in relation to hardness, following the protocol for Brinell Test (UNI EN 1534:2011). Due to the large width of rings, it was possible to run tests separately for both the limit of the ring and in the middle of the rings, to

Table 1 - Average, standard error and ANOVA test of wood basal density and shrinkage values in the three anatomical directions of the test pieces of the two plantations.

Site	Density	Shrinkage		
	g/cm3 ste	Tang % ste	Rad % ste	Long % ste
A	0.506 ±0.03	11.11 ±1.8	6.41 ±1.13	0.51 ±0.84
B	0.532 ±0.01	13.48 ±2.8	7.18 ±1.61	0.54 ±0.27
Average	0.519	12.243	6.781	0.746
P:	-	0.028**	0.036**	0.022**

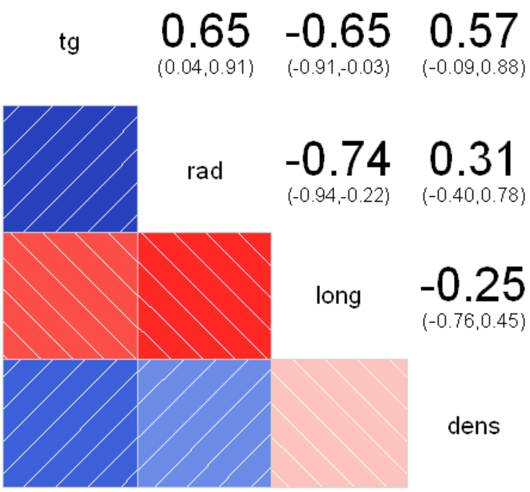

Figure 4 - Analysis of correlation with R package 'Corrgram'. In blue positive correlation, in red negative correlation. Pearson coefficients indicated on the right.

evaluate differences between them (Fig. 3). Finally, a radial sample containing the whole diameter was also taken from each disk, to assess the annual growth of the tree by measuring the rings.

The data were processed with R-package (R Core Team 2015).

Results and discussion

The trees felled had a diameter at breast height (DBH) of between 31cm and 48cm in plantation A and between 22cm and 41cm in plantation B. The disks taken at the base of the trees had an irregular shape, mainly caused by radical buttresses, with a diameter varying from 40 to 50cm; 4 disks had a small heartwood (in terms of wood tissues with darker colour) and in only 2 cases it was sufficiently extended to obtain 1-2 test pieces. This was probably due to the young age and relatively small diameters of the trees in both plantations. The felled walnuts showed diametric dimensions very close to the minimum required by the wood industry market (veneers) but the lack of heartwood makes them almost unusable. Nevertheless, the trees thinned out were sold to a sawmill and not for bio-energy production.

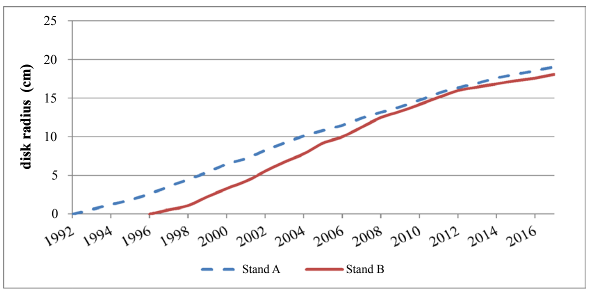

Figure 5 - Growth curves; average for each stand obtained from the measurements of the disks sampled.

The average percentage of sapwood humidity was 75.4% in plantation A and 62.4% in plantation B; this difference, not statistically significant, could be due to the different genetic material (not deriving from a dedicated selection), to the age of the trees and to the site environmental conditions. The sapwood basal density was, on average, 0.506g/cm^3 in plantation A, and 0.532g/cm^3 in plantation B. The difference between the two sites was not statistically significant; the values are lower than those found by Wani (Wani et al. 2014) for common walnut wood derived from 10-13-year-old plantations in Pakistan (between 0.59 and 0.66g/cm^3 based on site sampling), and from results reported by Brunetti (Brunetti et al. 2007) for common walnut samples measured before thermal treatment (between 0.67 and 0.72g/cm^3) but they are in line with some other research (Ostafi et al. 2016). In a recent study, some authors (Domini et al. 2018) evaluated the density of 12/65 conditioned samples, finding an average value of 584kg/m^3, much lower than our average value (892kg/m^3). The differences between the data obtained in this research (thinning of intensive plantations) and other data reported for the same species, often regarding natural stands, are probably due to the different percentage of juvenile wood. Table 1 shows the shrinkage values in the three directions (Tang= tangential, Rad= radial, Long= longitudinal) for sapwood test pieces. Also in this case our data are, in general, higher than the values reported by Domini et al. and more similar to the average data found in the literature. The Brinell test gives an average hardness of 4.4N/mm^2; the difference between the woods of the two plantations was statistically significant, while hardly any difference was evident between the two portions of the ring analysed (Tab. 2)

A correlation test was carried out between shrinkage and density; in figure 4, a 'correlogram' with Pearson indexes, produced using R-package, allows us to better understand the relations between these variables. We found high positive correlation (0.57) between density and tangential shrinkage and between tangential and radial shrinkage (0.65). A high negative correlation was found between radial and axial shrinkage.

The observation of the disk rings showed a good and almost regular growth width; differences in behaviour were found between the two plantations, probably due to layout and presence of other species (poplar in plantation B). In plantation A, it is possible to see a decrease of the average annual growth starting from the 16th year, probably due to the competition for some growth factors, rather

Table 2 - Average, standard error, and ANOVA test of Brinell values (N/mm2) of sapwood test pieces sorted by plantation and test position.

	Sample	Brinell (N/mm²)
Site	A	4.015 ± 0.81
	B	4.810 ± 0.96
Test position	On ring limit	4.475 ± 1.01
	In the middle of the ring	4.350 ± 0.94
Average		4.413
P:		
Site		0.007**
Test position		0.6

than to general climate differences. See the graph in Figure 5 shows that the polycyclic plantation (B), planted 4 years later, reached the tree diameters obtained in the pure plantation (A) in 2012. In this year it would probably have been economically advantageous to perform thinning, in order to keep the growth rate constant, which afterwards decreased slightly. In this case, poplar harvesting was done at the right time: only a slight decrease, followed by a quick restart, is barely visible on the red curve. We found an average increase respectively of 1.6cm/year and 1.3cm/year for the trees investigated.

Conclusions

Radial and tangential shrinkage, as well as hardness, were significantly different in the wood of the two plantations analysed. This cannot be ascribed to one specific factor only, due to the multiple differences between the two plantations: vegetal material (seedlings), site, layout and age. However, given the importance of these technological characteristics for an optimal use of wood at industrial level, the results obtained suggest the need for further studies on the physical-mechanical characteristics of walnut, taken in different conditions, as well on the relationship between the characteristics of wood, environment and cultivation practices. Bachtiar (Bachtiar et al. 2017) underlined the influence of moisture content on elastic properties of wood, while Wani (Wani et al. 2014) measured the wood density variation of common walnut and other species in different sites of India, finding a statistically significant variation, with a *range* from 0.59 to 0.66g/cm^3 for trees of 10-13 years. In a recent study, on a North-Eastern Italian plantation, the authors argued that eventually differences in values, compared with bibliography can be due to the young age of trees obtained from thinning. (Domini et al. 2018)

The observation of rings showed a good and quite regular tree growth, which demonstrates the correctness of the plantation layout, and of the cultivation protocol for both the pure and polycyclic plantation, the latter showing faster growth.

These results, together with the high variability of the data, confirm the need for further investigations, possibly associated with a complete and detailed knowledge of the characteristics of the plantations, the origin of the vegetal material and the agronomical operations carried out.

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